

Is the population trend of the Bearded Vulture *Gypaetus barbatus* in Upper Mustang, Nepal, shaped by diclofenac?

KHADANANDA PAUDEL, KRISHNA P. BHUSAL, RAJU ACHARYA, ANAND CHAUDHARY, HEM S. BARAL, ISHWARI P. CHAUDHARY, RHYS E. GREEN, RICHARD J. CUTHBERT & TOBY H. GALLIGAN

The Bearded Vulture (or Lammergeier) *Gypaetus barbatus* has been uplisted to Near Threatened because of declines throughout most of its range. In Upper Mustang, Nepal, the species underwent a substantial decline between 2002 and 2008. Diclofenac poisoning, through the consumption of contaminated livestock carcasses, is a serious threat to a number of scavenging raptors in South Asia. It is not known whether Bearded Vultures are intolerant to diclofenac; however, the timing and magnitude of the decline in Upper Mustang parallel those seen in the population of Himalayan Griffons *Gyps himalayensis* and the populations of six other South Asian vulture species, most of which are known to be intolerant to diclofenac. In this study, we continued the Upper Mustang survey for Bearded Vultures and use generalised linear models to examine the population trend between 2002 and 2014. We confirm a substantial decline after 2004 and show that this trend continued, albeit at a slower rate, up to 2014. However, we also show that subpopulations in remote valleys did not decline. We suggest that these trends are a strong indication that Bearded Vultures are intolerant of diclofenac and that the biology of the species and additional targeted threats are limiting its recovery in Upper Mustang.

INTRODUCTION

In 2014, the Bearded Vulture *Gypaetus barbatus* was uplisted to Near Threatened in response to declines observed throughout most of its fragmented range. The global population of the species is estimated to be between 2,000 and 10,000 individuals and it faces a range of concurrent threats, including direct persecution, non-targeted poisoning, nest-site disturbance, decreasing food supplies and collision with human-made structures (BirdLife International 2015).

Nepal once held one of the largest populations of breeding Bearded Vultures in the Himalaya (Gil *et al.* 2009). Two recent surveys of the species have taken place in the mountain district of Mustang. The first showed a 73–80% decline between 2002 and 2008 in Upper Mustang (Acharya *et al.* 2010) whilst the second showed a stable population in the Lower Mustang between 2002 and 2006 (Giri 2013), although the two surveys differed in their methods and therefore are not directly comparable. However, the number of individuals observed per day and per km in the Lower Mustang study—0.50–0.80 individuals/day and 0.03–0.05 individuals/km (Giri 2013)—were comparable with the rates observed at the end of the Upper Mustang study—0.76 individuals/day and 0.07 individuals/km (Acharya *et al.* 2010). The rates at the start of the Upper Mustang study were considerably higher—2.79 individuals/day and 0.35 individuals/km (Acharya *et al.* 2010). Because the timing of both surveys was similar, this evidence may suggest that a similar large decline did indeed occur in Lower Mustang, but before 2002 when the survey first took place.

Diclofenac poisoning is a serious threat to vultures in South Asia (Oaks *et al.* 2004, Green *et al.* 2004, 2007, Shultz *et al.* 2004). Vultures are exposed to non-steroidal anti-inflammatory drugs (NSAIDs), such as diclofenac, through the consumption of carcasses of recently treated livestock. Diclofenac was available in India from 1994, the same year that declines in vultures were first recorded there (Cuthbert *et al.* 2014) and in Nepal shortly after 1994, but declines in vultures there were first recorded in 2002 (Baral *et al.* 2004). Certainly, in 1995, in an area adjacent to Upper Mustang, a survey for Bearded Vultures showed encounter rates similar to those observed at the start of the Upper Mustang study—5.10 individuals/day and 0.38 individuals/km (Gil *et al.* 2009). Therefore, it is probable that declines in vultures occurred first in the lowlands and later in the highlands in Nepal. This conclusion seems logical given the differences in human cultures, agricultural practices, income and trade that differentiate the lowland and highland communities,

which led to diclofenac initially being more readily available and affordable in the lowlands.

Intolerance to diclofenac has been shown in *Gyps* vultures (Oaks *et al.* 2004, Swan *et al.* 2006, Das *et al.* 2010) and *Aquila* eagles (Sharma *et al.* 2014), both through experiments and examination of dead individuals found in the wild. It is not known whether Bearded Vultures are intolerant to diclofenac. However, the timing and magnitude of the decline in Upper Mustang are parallel to those seen in the population of Himalayan Griffon *Gyps himalayensis* in Upper Mustang (Acharya *et al.* 2009) and populations of six other vulture species in Nepal and India (Cuthbert *et al.* 2006, Prakash *et al.* 2007, Chaudhary *et al.* 2012), most of which are known to be intolerant to diclofenac. Since the 2006 ban on diclofenac in Nepal and India, declines in these populations of vulture have slowed, stabilised and possibly reversed (Prakash *et al.* 2012, Galligan *et al.* 2014). Most notable for this study is the almost complete recovery of the Himalayan Griffon in the Upper Mustang (Paudel *et al.* 2015).

In this study, we continued the Upper Mustang survey for Bearded Vultures for three years following the methods of Acharya *et al.* (2010). We combine their data with ours and examine the population trend between 2002 and 2014 using a refined method of analysis. We specifically tested whether the population decline in Bearded Vultures in Upper Mustang had slowed after the 2006 ban on diclofenac.

METHODS

The Upper Mustang, the northern part of the Mustang district, forms part of the arid trans-Himalayan zone, with steep peaks and deep valleys at altitudes above 2,850 m. Surveys were conducted in 2002, 2004, 2005, 2008, 2010, 2012 and 2014. Each survey commenced on or after 13 July and was completed on or before 18 September, which coincided with the end of the Bearded Vultures' breeding season. Variations in start and end dates were a result of adverse weather conditions delaying and/or suspending surveys.

Two to four surveyors were present on each survey, with at least one of them having participated in a previous survey. Surveyors used the main trails used by local people to travel between settlements as transects, which they walked, as the locals do. Surveys commenced at 08h00 and ended at 17h30 each day and a consistent walking pace with regulated rest periods was maintained throughout the day. All Bearded Vultures observed on both sides of each transect were counted and all sightings were confirmed by two or more surveyors.

Distinguishable plumage features, associated with age and/or moult patterns, and flight patterns (e.g. circling, flying), including altitude and direction, were agreed by the surveyors present and used to help identify individual vultures in order to avoid counting the same individual more than once.

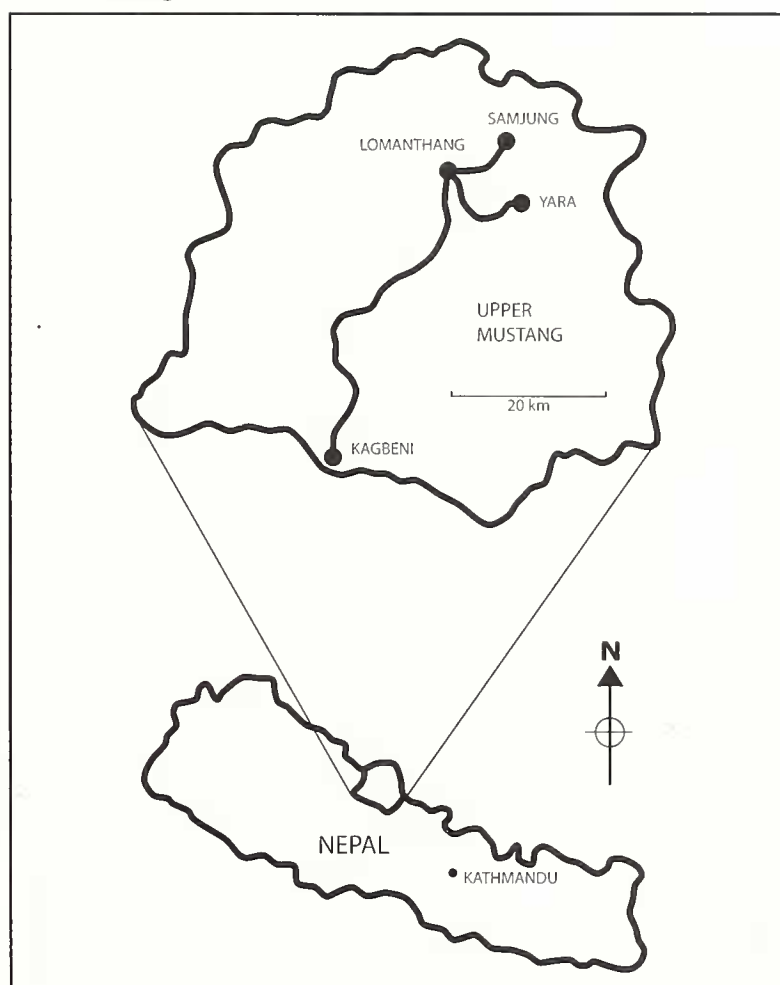
Acharya *et al.* (2010) surveyed four transects, although they were not mutually exclusive—two transects covered the same ground in opposite directions, three transects consisted of outward and return journeys along the same ground, and two transects radiated no more than 20 km from the same starting point, which is a short distance for a Bearded Vulture to fly. In surveys after 2010, we surveyed three transects (Figure 1) in one direction:

- 1) Kagbeni to Lomanthang (heading north-east), 47 km over 5–7 days
- 2) Lomanthang to Samjung (heading north-east), 12 km in 1 day
- 3) Lomanthang to Yara (heading south-east), 18 km over 1–2 days.

In this way, we avoided counting vultures along transects more than once. Furthermore, these transects followed the same routes as three transects used by Acharya *et al.* (2010), enabling us to use a subset of their data in our analysis. Neither the Lomanthang to Samjung nor the Lomanthang to Yara transects were surveyed in 2002. We recalculated walking distances along transects using Google Earth.

We analysed transects independently since our three transects radiated from Lomanthang. We considered the Kagbeni to Lomanthang transect to be our primary transect and used it to examine the population trend. We considered the other two transects to be secondary transects and used these to provide additional information on population trends. We calculated the number of Bearded Vultures along each transect on each survey day and survey km per transect. We examined the population trend along the primary transect by fitting a Poisson linear regression with time (year) elapsed since the first survey (2002 or 2004) as a continuous

Figure 1. Map of Nepal and Upper Mustang showing three transects: 1) Kagbeni to Lomanthang; 2) Lomanthang to Samjung; and 3) Lomanthang to Yara.



explanatory variable t and count as a response variable. We compared results from the linear regression to those of a quadratic ($t + t^2$) and cubic ($t + t^2 + t^3$) regression with F tests to test if changes in population change had occurred. In addition, we added altitude (m) reached at the end of the day as the continuous explanatory variable a and the interaction between t and a to the best model to test if altitude had an effect on population trends. We estimated the percentage mean annual rate of population change as $100 \cdot (1 - \exp(k))$, where k is the regression coefficient. Statistical analyses were performed in R (R Core Team 2015).

RESULTS

Along the primary transect, the total number of Bearded Vultures declined by 96.4%, from 28 to 1 (Table 1), between 2002 and 2008. A larger number of vultures was counted in the three subsequent years. Between 2002 and 2014, the total number declined by 89.3%, from 28 to 3 (Table 1, Figure 2). Our Poisson linear regression estimated a mean rate of population decline along our primary transect of 19.2% per year. Neither the quadratic nor cubic terms improved model fit significantly ($p > 0.2$), indicating that the number of vultures continued to decline throughout the study period. We found that altitude (Table 2) had no effect on population decline ($p > 0.6$).

Table 1. Total number, number per day and number per kilometre of Bearded Vultures counted on three transects and during seven survey years in Upper Mustang.

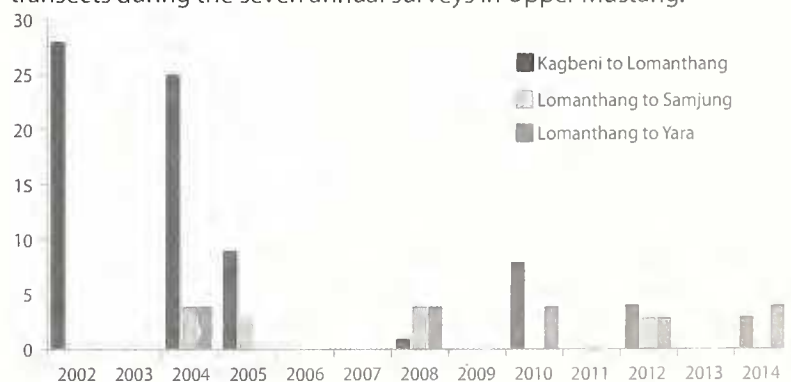
nc indicates that this transect–year combination was not surveyed.

Transect		2002	2004	2005	2008	2010	2012	2014
Kagbeni to Lomanthang	Total number	28	25	9	1	8	4	3
	number/day	4.00	3.57	1.29	0.17	1.33	0.67	0.60
	number/km	0.60	0.53	0.19	0.02	0.17	0.09	0.06
Lomanthang to Samjung	Total number	nc	4	3	4	0	3	0
	number/day	nc	4.00	3.00	4.00	0.00	3.00	0.00
	number/km	nc	0.33	0.25	0.33	0.00	0.25	0.00
Lomanthang to Yara	Total number	nc	4	0	4	4	3	4
	number/day	nc	4.00	0.00	4.00	4.00	1.50	4.00
	number/km	nc	0.22	0.00	0.22	0.22	0.17	0.22

Table 2. Total number of Bearded Vultures counted per survey day and survey year along the transect from Kagbeni to Lomanthang. Also shown is the altitude reached at the end of each survey day, whilst nc indicates that this transect–year combination was not surveyed.

Day	Altitude (m)	2002	2004	2005	2008	2010	2012	2014
1	2,950	3	3	0	1	0	0	0
2	3,600	7	6	2	0	2	0	nc
3	3,780	5	2	1	0	0	1	0
4	3,560	1	3	3	0	0	2	1
5	3,570	4	8	1	0	4	1	2
6	3,630	6	3	1	nc	nc	nc	nc
7	3,800	2	0	1	0	2	0	0

Figure 2. Total numbers of Bearded Vultures counted along the three transects during the seven annual surveys in Upper Mustang.



The total numbers of vultures counted on secondary transects were similar between 2004 and 2014. These numbers were more or less stable, with only four or fewer vultures per transect during the survey period (Table 1). Furthermore, the numbers of vultures per day and per km were similar for both secondary transects throughout the survey period (when vultures were present). In 2012 and 2014, similar numbers of vultures were counted along all three transects (Figure 2), but the number per day and number per km counted along the primary transect were considerably less than those counted along the secondary transects when vultures were present (Table 1).

DISCUSSION

We confirm the sudden and substantial decline in the population of Bearded Vultures in Upper Mustang between 2004 and 2008 (Acharya *et al.* 2010). In addition, we show that this trend continued, albeit at a slower rate, into the next decade. However, we also show no change in trend in remote valleys during the same period. The Bearded Vulture population trend contrasts with that of the Himalayan Griffon observed in Upper Mustang, which has substantially recovered (Paudel *et al.* 2015).

Upper Mustang is a small part of the range of Bearded Vultures in Nepal, so our results may not be applicable to the entire range of the species. In addition, our survey method meant that data were collected from a single short period in each year and were thereby possibly influenced by temporary differences in variables, such as weather conditions, ranging behaviour and food availability. This is particularly important for Bearded Vultures, which hold very large territories—tens of thousands of km² (Gil *et al.* 2014). Despite these limitations, our data, from a transect that we repeatedly surveyed, suggest a rapid then slower decline in the Bearded Vulture population. Hence, the population trend we report mirrors those of all seven vulture species presently being monitored in South Asia (Prakash *et al.* 2012, Galligan *et al.* 2014, Paudel *et al.* 2015). Our findings strengthen the case for diclofenac poisoning being the cause of the observed decline in Bearded Vultures in Upper Mustang. We know that diclofenac was available in Upper Mustang before the 2006 ban (Acharya *et al.* 2010). It seems possible that Bearded Vultures are not able to tolerate diclofenac given that it appears that one non-*Gyps* accipitrid, the Steppe Eagle *Aquila nipalensis*, cannot tolerate the drug (Sharma *et al.* 2014) and to date no accipitrids have been found to be tolerant of it. Bearded Vultures are probably also readily exposed to diclofenac residues in domesticated ungulate carcasses, either through bones, marrow or soft tissues because, despite specialising in consuming bones, this species also consumes soft tissues (Ferguson-Lees & Christie 2001, Margalida *et al.* 2009). It is perhaps curious that the rapid decline in Bearded Vultures in Upper Mustang appears not to have started until 2004 and to have continued until 2008; however, it probably started earlier, as it did in the White-rumped Vulture *G. bengalensis* in lowland Nepal (Prakash *et al.* 2012), and diclofenac was probably used after the ban until stocks ran out, but we lack the data to test these ideas.

Secondary poisoning (poison bait incidentally killing non-targeted species) does occur in Nepal and can kill large numbers of vultures per event, thereby causing local declines in vulture populations. However, the incidence of poison-baiting is likely to be far less than the use of diclofenac to treat domestic livestock prior to the ban (Paudel *et al.* 2016). For example, at least five poisoning events in which three Bearded Vultures perished each time would have had to occur in a single year (September 2004–June 2005) to cause the observed decline along the primary transect. Such a high frequency of secondary poisonings has never been recorded in Nepal (BCN unpublished data). Therefore, in Upper Mustang

the use of diclofenac to treat livestock is the most likely cause of the observed decline.

Why did we not see declines in populations of Bearded Vultures in remote valleys as we did in the larger populations in relatively less remote valleys? An obvious answer is that the decline was linked to human activities. Our primary transect, despite being only a walkable path, followed the main thoroughfare in the Upper Mustang—Kagbeni (with about 1,300 inhabitants), the start of the primary transect, is 8 km from road and air links with other Nepalese centres, whilst Lomanthang (900 inhabitants), at the end of the primary transect, has a road link with Chinese centres only 20 km further north, and hundreds of people live in the many villages and hamlets between Kagbeni and Lomanthang. In contrast, our secondary transects followed less frequently used paths to one or two small and remote hamlets. Given the greater human population, wealth and trade connections along the primary transect, veterinary use of diclofenac and thereby contamination of livestock carcasses was likely to be greater there than along the secondary transects. Other human activities that threaten Bearded Vultures might also be greater along the primary transect, including secondary poisoning and persecution, which we describe below. The secondary transects followed high altitude valleys, but given that altitude did not affect the decline along the primary transect, we do not think that altitude alone protected Bearded Vultures.

Why did we not see a recovery in the population of Bearded Vultures as we did for the population of Himalayan Griffons in Upper Mustang? Two possibilities that are not mutually exclusive are, first, that Bearded Vulture and Himalayan Griffon populations are not comparable in size and behaviour. Bearded Vultures hold vast territories and are therefore relatively scarce, whereas Himalayan Griffons are gregarious and relatively abundant. Paudel *et al.* (2015) suggested that Himalayan Griffons in Upper Mustang were able to recover quickly through regular influxes of large numbers of immature individuals during their annual migration from Central to South Asia, but lacked data to show this. In contrast, the recovery of Bearded Vultures in Upper Mustang is more likely to be reliant on the irregular addition of immature individuals during annual non-directional dispersal from Central Asia and probably remote valleys in the trans-Himalayan zone of Nepal, but we also lack data to show this. Second, unlike other vulture species, Bearded Vultures are subject to targeted persecution by local people in Nepal—adult birds are hunted for their intestines, which are used to treat diarrhoea, nestlings are collected to bring good fortune to households, and nests are disturbed or destroyed to recover rope and fabric that this species often uses as nest-building material (Acharya *et al.* 2010, KP pers. obs.). Such additional threats would impede the recovery of the species, although empirical evidence about the extent to which these activities threaten the species, in the Upper Mustang and elsewhere in Nepal, is lacking. Future conservation research should examine the impact of persecution on populations of Bearded Vultures throughout Nepal. If persecution is determined to be a serious threat, then advocacy and awareness programmes should be undertaken to ensure the survival of Nepal's globally important population of Bearded Vultures.

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Khadananda PAUDEL, Bird Conservation Nepal, PO Box 12465, Lazimpat, Kathmandu, Nepal and Kathmandu University, Dhulikhel, Kavreplanchowk, Nepal. Email: knpaudel@gmail.com

Krishna P. BHUSAL, Bird Conservation Nepal, PO Box 12465, Lazimpat, Kathmandu, Nepal.

Raju ACHARYA, Friends of Nature Nepal, P.O. Box 23491, Sundhara, Kathmandu, Nepal.

Anand CHAUDHARY, Bird Conservation Nepal, PO Box 12465, Lazimpat, Kathmandu, Nepal and The Institute of Ecological, Earth and Environmental Sciences, Baylor University, One Bear Place #97205, Waco, TX 76798, USA.

Hem S. BARAL, Zoological Society of London, PO Box 5867, Kathmandu, Nepal.

Ishwari P. CHAUDHARY, Bird Conservation Nepal, PO Box 12465, Lazimpat, Kathmandu, Nepal.

Richard J. CUTHBERT, Conservation Solutions, 9 Prospect Drive, Belper, Derbyshire DE56 1UY, UK.

Rhys E. GREEN, RSPB Centre for Conservation Science, RSPB, The Lodge, Sandy SG19 2DL, UK and Conservation Science Group, Department of Zoology, University of Cambridge, David Attenborough Building, Cambridge CB2 3QZ, UK.

Toby H. GALLIGAN, RSPB Centre for Conservation Science, RSPB, The Lodge, Sandy SG19 2DL, UK.